Terminal Report to NASA

Grant No. NsG 222-61

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To: Technical Reports Officer
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Office of Space Science and Applications
National Aeronautics and Space Administration
Washington, D. C. 20546

Covering the Period 1961 through Oct. 15, 1965

Massachusetts Institute of Technology
Cambridge, Mass.

Terminal Statement for Research

Grant No. NsG 222-61

This research has been concerned chiefly with Rb-Sr age studies of tektites and studies of the major element compositions of tektites. In these two areas contributions have been made, both in contributions to the bulk of the chemical data on tektites and to the theory of origin of the tektites. The results of most of this work has been published, and the publications which have been sponsored by NASA Research Grant No. NsG 222-61 are listed at the end of this terminal report, along with abstracts from some of the publications, professional paper presentations, and theses.

Thirty-five new major element analyses of tektites (Schnetzler and Pinson, 1964a, 1964b) have been published, and an additional twenty-three analyses of moldavites is now in press (Philpotts and Pinson, 1965). The significance of this work is two-fold. It has provided a substantial increase in the number of reliable analyses of tektites from the various localities. Barnes (1940, U. of Texas Publ. No. 3945) had compiled sixty-one published analyses. Of the ninety analyses published subsequent to this compilation by Barnes, fifty-eight are our work. We consider these analyses to be especially trustworthy because they were all carefully monitored using G-1 and W-1 as accuracy standards and because all of the analyses were accomplished in one laboratory, giving a uniformity of quality to them. The analytical data for the twenty-three moldavites has been used (Philpotts, 1965; Philpotts and Pinson 1965) to demonstrate that the chemical variability of the moldavites is due to a process of selective volatilization during the fusion event, rather than to chemical differentiation due to any normal igneous processes. The invariant Sr isotopic composition of the moldavites (Pinson, Schnetzler, Philpotts, and Fairbairn, 1966) coupled with their variable chemical compositions, and the negative correlations between the alkali and alkaline earth elements suggests that the parent material of the moldavites was of nearly constant chemical and Sr isotopic composition throughout, and that the present variations in chemical compositions are due to selective volatilization. Similar data for the Ivory Coast tektites strengthens this theory.

The Rb-Sr age correlation studies of tektites at first led us to believe that the tektites had been splashed off the surface of some extra terrestrial planet, possibly the Moon. This hypothesis, which we now believe to be erroneous, was based on the discovery that the southwest Pacific tektites, the moldavites, and the North American tektites form a 400 million year Rb-Sr isochron (Schnetzler and Pinson, 1964). The improbability of three separate meteorite impacts fusing rocks of just that age (400 m.y.) seemed so high that we suspected that the impacts must have occurred on the surface of another planet and that the surficial rocks (to a depth of perhaps a kilometer) on that planet were of uniform Rb-Sr age. To further check our hypothesis we needed samples of Ivory Coast tektites. These were unobtainable until recently, when we acquired a large collection of Ivory Coast tektites. Results of work on these samples (Schnetzler and Pinson, and Hurley, 1965) show that the Ivory Coast tektites indeed do not fall on the 400 m.y. isochron, but lie on an isochron 2000 m.y. old, with rocks from the vicinity of the Bosumtwi Crater in Ghana. Impact glasses from the crater area also lie on this isochron. Like the moldavites, the Ivory Coast tektites have almost invariant Sr isotopic compositions, but variable chemical compositions. Both have Rb/Sr ratios that vary over a range of about 30%.

It has been demonstrated by other workers that the K^{40}/A^{40} age of the moldavites of 15 m.y. is identical to the age of the Ries Kassel basin meteorite impact crater. The variety of rock types of ages ranging from middle Paleozoic (at depth) to Miocene makes a Rb-Sr age of 400 m.y. not unreasonable for glass (the moldavites) derived from the fusion of such rocks.

More convincing is the data for the Ivory Coast tektites and the rocks and impact glass of the Bosumtwi crater. K^{40}/A^{40} ages of 1.3 m.y. for both have been reported by other workers, and our Rb-Sr isochron age of 2000 m.y. for both is taken as evidence that the Ivory Coast tektites were fused from ancient country rocks at the Bosumtwi crater site.

We presently possess a very fine collection of 75 Ivory Coast tektites. The compositions, shapes, physical characters, etc. of these tektites are typical of those of tektites, so that, if it has been demonstrated that the Ivory Coast tektites and the moldavites are

terrestrially derived by impact from adjacent craters located at distances of several hundred kilometers, then the other two tektite groups probably were similarly derived from terrestrial craters whose locations are as yet undiscovered.

The important work of Chapman on the aero dynamic shapes of tektites, and his theoretical and experimental demonstration that these tektites must have been extra-terrestrial remains a formidable refutation of a terrestrial origin, and is in paradoxical conflict with the present K/A and Rb/Sr age data which so strongly suggests a terrestrial origin for two of the four groups of tektites. We can suggest that some mechanism for removing the atmosphere from the region of the meteorite impact site blast exists that is not as yet understood.

In conclusion, it is my opinion (Pinson) that both the Ivory Coast and the Czechoslovakian tektites and probably the other two groups of tektites are of terrestrial origin.

Below are tabulated some abstracts from published papers of research supported by NsG 222-61

A report on some recent major element analyses of tektites
C.C. Schnetzler and W.H. Pinson Jr.
Geochim. et Cosmochim. Acta 1964, 28, 793-806.

Abstract- Forty-two tektites and two "amerikanites" were partially or completely analysed for major elements. Included were 7 moldavites, 1 bediasite, 2 javanites, 15 philippinites, 12 indochinites and 5 australites. Many chemical similarities are noted between the philippinites and indochinites, but the two groups appear different in SiO_2, Al_2O_3, TiO_2 and, in particular, CaO contents. No decrease in alkali element content is observed from Indo-China to the Philippine Islands (i.e. west to east) as is observed across Australia. Selective volatilization can not account for the differences in the two groups. Perhaps the higher CaO and Sr contents of the philippinites are due to contamination of the parent material by limestone. The CaO contents of the indochinites analysed are distinctly lower, and the MgO contents higher, than the analyses reported in Barnes (1940). Real variations, up to approximately 10 per cent for some constituents, exist within the philippinites and indochinites, and even within tektites from restricted sites. Tektites from two sites in the Philippine Islands are identical, within experimental error, in mean composition. The unity of chemical character of the australites and the southeast Asian tektites strongly suggest that they represent one large strewn field. New moldavite analyses do not indicate any systematic chemical variation across the Czechoslovakian strewn field.

Variation of strontium isotopes in tektites
C.C. Schnetzler and W.H. Pinson Jr
Geochim. et Cosmochim. Acta, 1964 28, 953-969.

Abstract- The rubidium, strontium, and strontium isotopic compositions have been determined in tektites from Indo-China, Philippine Islands, Java, Australia, Texas, Georgia, Massachusetts and Czechoslovakia. The range of Sr^{87}/Sr^{86} ratios in 18 tektites is from 0.7121 to 0.7223, indicating the results of Pinson et al. (1958), reporting no radiogenic strontium in tektites, were not of sufficient precision to study the problem definitively. This range

Variation of strontium isotopes in tektites

Abstract - of Sr^{87}/Sr^{86} ratios is quite small compared to the range found in nature, in general agreement with previous studies of oxygen and silicon isotopes in tekties. Rb and Sr contents of tektites from a given locality are very similar, but differences exist between localities. There is indicated, however, a sympathetic variation of the Sr^{87}/Sr^{86} and Rb/Sr ratios, i.e. the tektite groups have age values of approximately 400 m.y. If tektites were derived from the Moon, and the surface of the Moon is old (4.5 b.y.), the observed Sr^{87}/Sr^{86} ratios could not have been developed by a chondritic, granitic, or tektitic surface material, but could have been generated by a basaltic type material. However, production of tektites from a basaltic type surface material during a high temperature fusion implies extreme fractionation in a direction contrary to expectation. A second possibility is that the Moon has undergone differentiation within the last 500 m.y.

Comparison of the Rb-Sr age of the Bosumtwi crater area, Ghana, with the age of the Ivory Coast tektites

C. C. Schnetzler

Submitted to Science for publication, October 1965

Abstract- Rocks from the vicinity of Bosumtwi crater, Ghana, and a representative collection of Ivory Coast tektites have been analyzed mass spectrometrically for rubidium, strontium, and strontium isotopic composition. The data from the crater area rocks yield an age of 1.97×10^9 years ($\lambda_{Rb} = 1.47 \times 10^{-11}$ year^{-1}). The Ivory Coast tektites plot on this isochron. This identity of age values for the Ivory Coast tektites and the Birrimian basement rocks of West Africa strongly supports the hypothesis of terrestrial formation for these tektites. The evidence available at present suggests the Ivory Coast tektites are most probably the fusion products of meteoritic impact at the Bosumtwi crater site.

K/Rb ratios in tektites

W.H. Pinson, Jr., J.A. Philpotts, and C.C. Schnetzler

Journal of Geophysical Research, v.70, No.12, June 15, 1965

Abstract- K/Rb weight ratios and individual K and Rb contents are reported for 54 tektites. Twenty-nine of these analyses are new. The ranges of K/Rb ratios

K/Rb ratios in tektites

Abstract

found in the present investigation for tektites from the different localities are: australite, 151-185, 4 samples; javanite, 162; philippinites, 169-174, 7 samples; indochinites, 166-178, 8 samples; Ivory Coast, 209; moldavites, 197-238, 30 samples; North America, 249-267, 3 samples. Thus the Pacific area, North American, and Czechoslovakian tektites fall into three distinctive K/Rb ratio groups. Potassium was determined by flame photometry, 23 of the moldavite analyses being confirmed by X-ray fluorescence. Rubidium was determined by X-ray fluorescence with standardization and numerous cross checks by mass-spectrometric and stable-isotope-dilution analyses. G-1 and W-1 were used as analytical monitors. Precision and accuracy for the ratios are better that $\pm$ 4%. Variations of the K/Rb ratios within a group are interrupted as resulting from differential volatilization rates for K and Rb during high-temperature fusion, whereas differences between the geographical groups are thought to reflect initial compositional variations in the parent materials.

Abstracts of some Papers Given at Professional Meetings

American Geophysical Union Program
Abstracts for April, 1961

W.H.Pinson and C.C.Schnetzler (Massachusetts Institute of Tehcnology, Cambridge, Mass.) Rb-Sr Correlation Studies of Tektites -- Reanalyses of tektites have revealed that they do contain measurable quantities of radiogenic Sr. Earlier analyses (Pinson), reporting tektite Sr to be of normal isotopic composition, were in error. By direct mass spectrometric measurements the 87/86 ratios of eleven tektites ranged from 0.7168 to 0.7215, averaging 0.7185 ± 0.0005 (standard deviation of the mean). Included are Philippinites, Indo-Chinites, Australites, a Bediasite, and a tektite from Martha's Vineyard. Two Moldavites yielded 0.7257 and 0.7235. Triplicate isotope ratio analyses on two Indo-Chinites gave a standard deviation of a single analysis of 0.0010 and 0.0007. K-Ar analyses (Reynolds) indicate a fusion date of less than 30 m.y. for all tektites, in fact less than 1 m.y. for Pacific area tektites. Only a negligible increase in 87/86 could have occurred in 30 m.y. The measured ratios are essentially the same as at the time of fusion. It appears that tektites exclusive of Moldavites may be correlated into a single group on the basis of their 87/86 ratios. Strikingly low water contents (Friedman are evidence of very high fusion temperatures, which might have disturbed Rb/Sr ratios by fractionation. If the measured Rb/Sr ratios are applied and any initial Rb/Sr value is assumed, two calculated age value groups emerge. If initial 87/86 = 0.712, 200 m.y. is obtained for Pacific area tektites, and 300 m.y. for the Bediasite, Martha's Vineyard tektite, and the Moldavites.

American Geophysical Union Program
Abstracts for April, 1962

C.C.Schnetzler and William H. Pinson, Jr. (Massachusetts Institute of Technology, Cambridge) A Study of the Chemical Composition of Tektites from the Southeast Pacific. Thirty-four new major-element tektite analyses are given below, the numbers in parantheses representing numbers from each locality (see table on next page).

Abstracts

	Philippinites (15)	Indochinites (12)	Javanites (2)	Australites (5)
SiO	70.8	73.0	70.2	71.3
Al_2O_3	13.85	12.83	12.29	13.96
Fe_2O_3	0.70	0.64	0.71	0.65
FeO	4.30	4.37	5.86	3.95
MgO	2.60	2.48	4.47	2.11
CaO	3.09	1.91	2.47	3.50
K_2O	2.40	2.40	1.96	2.39
Na_2O	1.38	1.45	1.10	1.43
TiO_2	0.79	0.73	0.68	0.72
MnO	0.09	0.09	0.12	0.09

Small differences in Ti, Si, and Al, and a large difference in Ca contents between indochinites and philippinites are established. However, the chemical similarities (confirmed also by trace-element and isotope studies) are more striking than the differences. For example, the K/Na, Fe/Mn, and Fe^{2+}/Fe^{3+} ratios are identical in three of the groups, and all four groups possess a unity of chemical character which to us excludes any random process of formation, such as 4 separate meteoritic impacts. However, difficulties (such as their peculiar geographical distributions) of fitting the compositional data to the hypothesis of one big meteoritic splash cause us to favor an extra-terrestrial origin.

American Geophysical Union Program
Abstracts for April, 1965

W H.Pinson (Dept. Geology and Geophysics, Massachusetts Institute of Technology, Cambridge), C.C.Schnetzler (Goddard Space Flight Center, Greenbelt, Md.), J.A.Philpotts and H.W.Fairbairn (Dept. of Geology and Geophysics, Massachusetts Institute of Technology, Cambridge, Rb-Sr Correlation Study of the Moldavites. Rb contents from 96 to 160 ppm and Sr from 124 to 157 ppm have been determined for 31

Abstracts

moldavites. Rb/Sr ratios range from 0.77 to 1.20. Precision of the ratios is 4%. Nine of the samples have been analyzed isotopically. Sr^{87}/Sr^{86}, normalized to 0.1194 for Sr^{86}/Sr^{88}, ranges from 0.7208 to 0.7224. Excepting one analysis, the range of the other eight analysis is 0.0011, which is two standard deviations of a single analysis. There is no sympathetic variation between Sr isotopic compositions and Rb/Sr ratios. We interpret this to mean that during fusion either either Rb or Sr was lost differentially. The fusion event would not fractionate the Sr isotopes. Both the Bohemian and Moravian strewn fields are represented in the sampling, and the Rb-Sr data do not distinguish the two areas. Two hypotheses are suggested. Firstly, the parent material was chemically and geochronologically homogeneous, over the whole crater area and in depth. This is incompatible with the hypothesis that the moldavites were blasted off the Nördlingen-Ries crater, for the rim rocks there exhibit a great variety of types. Furhtermore, there is apparently no chemical relation between the crater impact glass and the moldavites. The second hypothesis is that a remarkable homogenization of the parent-material Sr occurred during the fusion event, which allowed a variation in chemical compositions to arise through selective volatilization of the elements. However, lechatelierite occurs in the moldavites, and survival of discrete phases might not be expected in material subjected to such thorough homogenization. Under this second hypothesis the presence of lechatelierite might best be explained as a post-mixing phase separation, but this phenomenon is not predicted and has not been demonstrated experimentally.

American Geophysical Union Program
Abstracts for April, 1965

C.C.Schnetzler (Goddard Space Flight Center, Greenbelt, Md.), W.H. Pinson, and H.W.Fairbairn (Massachusetts Institute of Technology, Cambridge, Mass.), Rb-Sr analyses of Two Ivory Coast Tektites. Two Ivory Coast tektites have been analyzed mass spectrometrically for rubidium, strontium, and strontium isotopic composition. The results are: Rb = 65 ppm, Sr = 304 ppm, Sr^{87}/Sr^{86} = 0.7232 for one sample, and Rb = 64 ppm, Sr = 394 ppm, Sr^{87}/Sr^{86} = 0.7188 for the other sample. Thus, these tektites do not lie in the 400 m.y. isochron reported for the other three known groups of tektites, the Australasian tektites, the South American tektites, and the moldavites. The Ivory Coast tektites appear to have been fussed from much older material (circa 2×10^9 years) than the other groups of tektites.

Abstracts from Theses

(1) John Aldwyn Philpotts - The Chemical Composition and Origin of Moldavites
Submitted to the Department of Geology and Geophysics at M.I.T. in March, 1965, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract: Twenty three new major-element analyses of moldavites are reported. The samples include seventeen Bohemian and six Moravian tektites. The ranges in the contents of the various oxides are as follows: SiO_2, 75.5 - 80.6; Al_2O_3, 9.62 - 12.64; TiO_2, 0.268 - 0.460; Fe_2O_3, 0.12 - 0.31; FeO, 1.42 - 2.36; MgO, 1.13 - 2.50; CaO, 1.46 - 3.71; Na_2O, 0.31 - 0.67; K_2O, 3.26 - 3.81. The Rb and Sr contents and the Rb/Sr ratios are also reported for the 23 specimens; the ranges are as follows: Rb, 120 - 160 ppm; Sr, 130 - 156 ppm; Rb/Sr. 0.82 - 1.20. The specific gravity and refractive index values range from 2.3312 to 2.3718 gm/cm^3 and from 1.486 to 1.495, respectively. In contrast to the australites, the moldavites display significant negative correlations between the alkali metals (Na and Rb) and the alkaline earths. The variations in the chemical composition of moldavites would seem to be unlike those of sedimentary or igneous rocks. It is suggested that the parent material of the moldavites was of constant chemical composition throughout and that the present variations in composition are due largely to selective volatilization. The wide range of Rb/Sr ratios in conjunction with the uniformity of the Sr isotopic composition supports this suggestion. The australite data is briefly examined in terms of selective volatilization. It is suggested that the Nordlingen Ries crater may have been produced by the impact of the moldavite parent-body.

(2) Jae-Young Hwang - Spectrochemical Analysis of the Moldavites (Ba, Li, Sr, and Rb)
Submitted in partial fulfillment of the requirement for the degree of Master of Science at M.I.T., September, 1964.

Abstract: Spectrographic analysis of twenty-six Moldavites was made on the elements of barium, lithium, strontium, and rubidium using G-1 and W-1 as standard mixtures.

Abstracts from Theses

(2) Jae-Young Hwang

The concentration of each element found ranges from 848 to 1220 in barium, 18 to 27 in lithium, 61 to 153 in strontium, and 94 to 155 in rubidium with average relative deviations of 15.5, 8.9, 21.1, and 13.1% respectively.
The relative accuracies of strontium and rubidium determinations by spectrographic method was compared with those by X-ray fluorescence analysis with average errors of 29.0 and 14.5% respectively.
The regional variations of the elements in the Moldavites were found insignificant within the experimental errors.
On the basis of strontium, rubidium, and lithium contents it was found that the Moldavites are most similar to the low-calcium granite, while rubidium-strontium ratio most closely resembles to that of shale.

Below are listed the academic and graduate student staff supported by Research Grant No. NsG 222-61. Drs. Schnetzler and Philpotts are now employed as geochemists by NASA working on problems of space chemistry.

1. Schnetzler, C.C., Ph.D. dissertation. Supported for 1½ years as a graduate student Research Assistant and for 2 years as a post-doctoral Research Associate at M.I.T.
2. Philpotts, J.A., Ph.D. dissertation. Supported for 3 years as a graduate student Research Assistant, and for 2 months as a post-doctoral Research Assistant.
3. Hwang, Jae, M. S. dissertation. Supported for 2 years as a graduate Research Assistant.
4. Mrs. Marla Moody Heath, supported for 1 year as a graduate Research Assistant
5. Pinson, W.H., Project Supervisor.

Publications, sponsored by NsG 222-61

Chase, J.W., Schnetzler, C.C., Czamenske, G.K., and Winchester, J.W., 1963, Rare earth element content of a tektite, J. of Geophys. Res., 68, 577-579.

Hwang, Jae Young, 1964, Spectrochemical analysis of the moldavites, M. S. Thesis at the Mass. Institute of Technology.

Philpotts, J.A., 1965, The chemical composition and origin of moldavites, Ph.D. Thesis at the Mass. Institute of Technology.

Philpotts, J.A., and Pinson, W.H., 1965, The chemical composition and origin of moldavites, (in press), submitted to Science in October 1965.

Pinson, W.H., Philpotts, J.A., and Schnetzler, C.C., K/Rb ratios in tektites, 1965, J. of Geophys Res., 70, No.12, 2889-2994.

Pinson, W.H., and Schnetzler, C.C., 1962, Rb-Sr correlation of three tektites and their supposed sedimentary matrices, Nature, London, 193, 233-234.

Pinson, W.H., Schnetzler, C.C., Philpotts, J.A., and Fairbairn, H.W., 1966, Rb-Sr age study of moldavites, prepared and to be submitted to J. of Geophys. Res., for publication.

Schnetzler, C.C., and Pinson, W.H., 1963, The Chemical Composition of Tektites, Chapter 4 in the book, Tektites, edited by John A. O'Keefe, The University of Chicago Press, 95-129.

Schnetzler, C.C., and Pinson, W.H., 1964, A report on some recent major element analyses of tektites, Geochim. et Cosmochim. Acta, 28, 793-806.

Schnetzler, C.C., and Pinson, W.H., 1964, Variation of Sr isotopes in tektites, Geochim. et Cosmochim. Acta, 28, 953-969.

Schnetzler, C.C., Pinson, W.H., and Hurley, P.M., 1965, Comparison of the Rb-Sr age of the Bosumtwi crater area, Ghana, with the age of the Ivory Coast tektites, (in press), submitted to Science in October 1965.